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RESEARCH MEMORANDUM

SOME FACTORS AFFECTING THE VARIATION OF PITCHING MOMENT

WITH SIDESLIP OF AIRCRAFT CONFIGURATIONS

By Edward C. Polhamus

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SOME FACTORS AFFECTING THE VARIATION OF PITCHING MOMENT

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SUMMARY

A brief study of available wind-tunnel data with regard to the variation of pitching moment with sideslip has been made. The results indicate that the effect of sideslip on the pitching moment can be large and is dependent upon a large number of factors. For example, it was found that wing plan form, wing position, horizontal-tail location, aileron location, and fuselage shape can have appreciable effects on the pitching moment due to sideslip. However, data at large sideslip angles are rather meager and a considerable amount of systematic experimental data is needed, especially at transonic and supersonic speeds.

INTRODUCTION

During recent flight tests of a research airplane having a low-aspect-ratio straight wing and of a fighter airplane employing a swept-back wing (ref. 1), violent coupled pitching and yawing motions were encountered following abrupt aileron rolls. These motions were characterized by the attainment of large angles of attack and sideslip which were sufficiently violent to cause the pilot to lose control of the airplane and could easily result in structural failure for conditions of high dynamic pressure. It should be pointed out that somewhat similar violent motions also have been encountered by fighter-type airplanes following pull-ups and abrupt rudder kicks.

The large variations of angle of attack encountered result in part from the fact that modern high-speed aircraft tend to be heavily loaded along the fuselage and therefore are inclined to roll about the principal axis rather than the stability axis, thereby resulting in a cyclic variation of angle of attack with roll angle (varies from α to β to $-\alpha$ in 180°). The variation of pitching moment with sideslip also is an important factor and under some conditions may have a significant influence on the aircraft motions. However, with the possible exception of investigations of low-speed propeller-driven configurations with their

large slipstream effects (see ref. 2 for example), it appears that relatively little information with regard to the variation of pitching moment through large sideslip angles is available. Furthermore, much of the information that has been published has not been analyzed, inasmuch as it is usually presented only incidentally with respect to the usual lateral-stability data.

The purpose of this paper, therefore, is to summarize briefly wind-tunnel results, both published and unpublished, regarding the effect of sideslip on the pitching moments. Because of a lack of sufficient data, the information contained herein can be considered only as illustrative of some of the more important factors affecting the variation of pitching moment with sideslip angle and as a possible guide to future systematic studies and correlations, rather than as a source of design information. Inasmuch as little data are available at high subsonic and supersonic speeds, the results presented are, for the most part, limited to low subsonic speeds. In order to expedite publication, only a limited analysis is made and no attempts to estimate the various effects theoretically have been made.

SYMBOLS

The coefficients used herein are presented with respect to the stability system of axes (see fig. 1). Since this system of axes sideslips with the model, the pitching moments presented are the same as would be obtained with respect to the body axes. All pitching moments are given about the 25-percent-chord point of the wing mean aerodynamic chord.

A aspect ratio, b^2/S_W

c_l section lift coefficient, $\dfrac{\text{Section lift}}{qc}$

C_L lift coefficient, $\dfrac{\text{Lift}}{qS_W}$

C_l rolling-moment coefficient, $\dfrac{\text{Rolling moment}}{qS_W b}$

C_m pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qS_W \bar{c}}$

q dynamic pressure, $\dfrac{\rho V^2}{2}$, lb/sq ft

ρ air density, slugs/cu ft

V   velocity, ft/sec

c   local wing chord, ft

c_{av} average wing chord, ft

$\bar{c}$ wing mean aerodynamic chord, ft

b   wing span, ft

S_w wing area, sq ft

S_t horizontal-tail area, sq ft

l_t horizontal-tail length, (distance between quarter-mean-aerodynamic-chord points of wing and tail), ft

η nondimensional spanwise ordinate based on wing semispan

α angle of attack, deg

β angle of sideslip, deg

δ_a aileron deflection (in plane perpendicular to hinge line), deg

Λ sweep of wing quarter-chord line, deg

λ taper ratio, $\dfrac{\text{Tip chord}}{\text{Root chord}}$

M   Mach number

·DISCUSSION

Wing Characteristics

Sweep effect.- Although relatively little experimental data through a range of sideslip angles are available for isolated wings, it appears that sweep has probably the largest effect on the wing-alone variation of pitching moment with sideslip. This is illustrated in figure 2 where the results are presented for wings of aspect ratio 5.2 having sweep angles of 0°, 30°, and 45° from the systematic investigation reported in reference 3 and for a 60° sweptback wing of aspect ratio 3.5 from reference 4. The results from the three wings of the systematic series indicate that, although there is relatively little effect of sideslip angle on the pitching moments of the unswept wing, rather appreciable effects, consisting of negative increments of pitching moment due to

sideslip, are present for the two moderately sweptback wings and these effects increase with increasing sweep angle. Pressure distributions have been obtained for these wings (see ref. 5) and the results indicate that for the sweptback wings the loss of lift on the trailing wing due to side-slip is considerably greater (especially at high sideslip angles) than the gain of lift on the leading wing and that the greatest portion of the loss occurs over the inboard portion of the wing (see sketch 1).
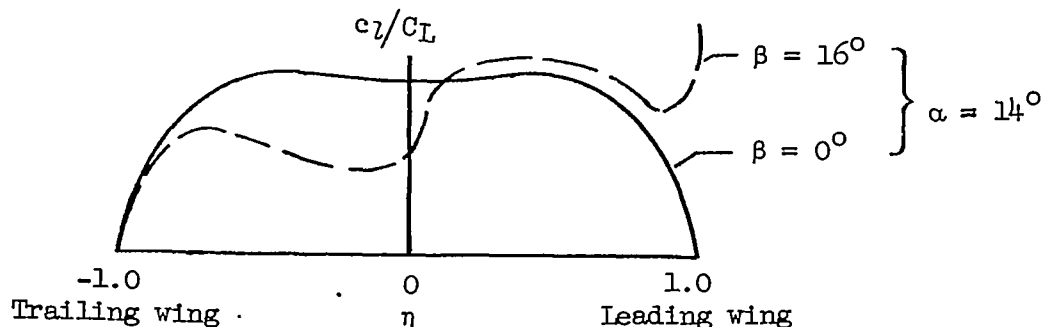
Sketch 1.

Since this inboard portion of the wing lies ahead of the aerodynamic center of the unsideslipped wing, a negative increment in pitching moment occurs due to sideslip. In addition, the results indicate that the largest portion of the gain in lift on the leading wing occurs at the tip which also results in a negative increment of pitching moment.

The major differences between the loadings of the leading and trailing wing can be explained by simple sweep theory, in which the lift on the trailing wing decreases by the factor $\dfrac{\cos(\Lambda + \beta)\cos\beta}{\cos\Lambda}$

whereas on the advancing wing it increases by the factor $\dfrac{\cos(\Lambda - \beta)\cos\beta}{\cos\Lambda}$ thereby resulting in greater effect on the trailing wing, and by the fact that the center of load moves outboard with increasing sweep (side-slip in this case). It should be pointed out that the differences in loading between the leading and trailing wings actually are greater for wings of moderate sweep ($\Lambda = 30°$) but because of the greater moment arms associated with the $45°$ wing the effect of sideslip on pitching moment is greater for this wing.

With regard to the $60°$ sweptback wing of aspect ratio 3.5 (lower right part of fig. 2), it will be noted that except for the angle of attack of $5.6°$ the effect of sideslip on the pitching moment is opposite that for the other wings. This is apparently due to the fact that this wing is the only one (of those presented) for which sideslip data were

obtained above the angle of attack corresponding to pitch-up ($\alpha \approx 11^{\circ}$ for this wing). Since the pitch-up characteristics of sweptback wings occur at progressively lower angles of attack as the sweep angle increases (see ref. 6 for example), with the greatest change occurring in the high sweep range, it might be expected that, for a sweptback wing in sideslip, the change in the tip stalling would be more pronounced on the trailing wing and would result in a positive increment of pitching moment due to sideslip. This result is illustrated in sketch 2 which is based on data from reference 4.
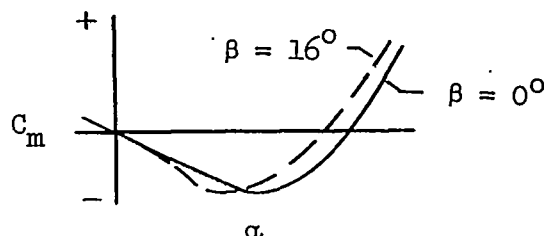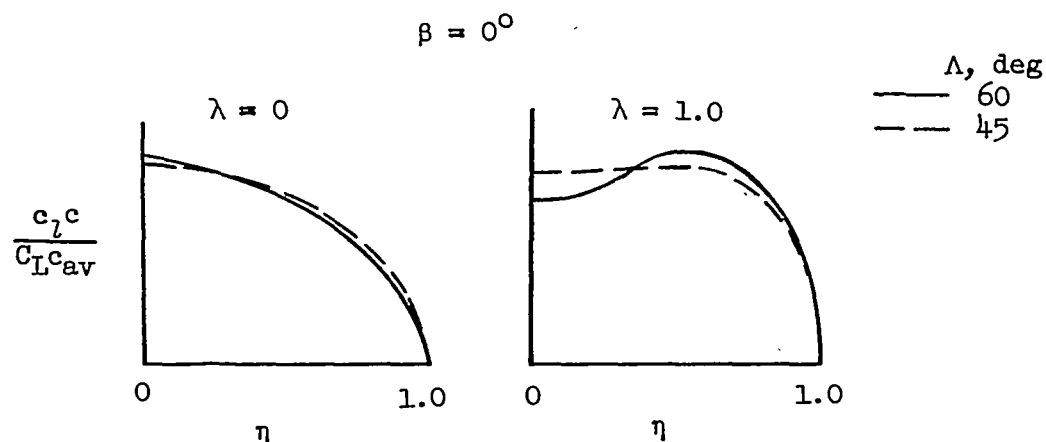

Sketch 2.

In the sketch the curves of pitching moment against angle of attack are shown for the condition of zero sideslip and a sideslip angle of 16°, and it will be noted that the pitch-up occurs somewhat earlier in the sideslipped condition - resulting in positive increments of pitching moment due to sideslip at the higher angles of attack.

Effect of taper and aspect ratio.- The effect of wing taper ratio on the variation of pitching moment with sideslip angle as determined from the systematic low-speed investigation reported in reference 3 is presented in figure 3 along with an indication of possible aspect-ratio effects.

With regard to taper ratio, the data indicate a considerable reduction in the variation of pitching moment with sideslip angle as the wings are made more highly tapered (lower value of taper-ratio parameter λ). Unfortunately no experimental pressure distributions appear to be available for the tapered wings. It would seem, however, that the reason for the negligible effect of sideslip on the highly tapered wing is associated with the fact that the effect of sweep angle on the span load distribution of unsideslipped wings decreases as the wings become more tapered (see. ref. 7 and sketch 3).

$$\beta = 0^\circ$$

Sketch 3.

This fact suggests that, although there is an overall loss of lift associated with sideslip, there is little change in the location of the load centers for highly tapered wings and therefore little change in the pitching moment for a given angle of attack.

Considering the possible effect of aspect ratio on the variation of pitching moment with sideslip, one might surmise that, inasmuch as the effect of wing sweep on the lift and span loading diminishes as the aspect ratio is reduced, the effect of sideslip on pitching moment would likewise diminish with decreasing aspect ratio. A comparison of the results for the wing of aspect ratio 5.2 (ref. 3) and a similar wing of aspect ratio 3.6 (ref. 8) is presented in the top part of figure 3 and appears to substantiate this reduction with decreasing aspect ratio; however, a systematic investigation over a larger aspect-ratio range is needed to define this effect fully.

Effect of ailerons.- The lift produced by high-lift flaps (both deflected in same direction) decreases with sideslip on a sweptback wing because there is a greater effect of sideslip on the lift of the flap on the trailing wing than on the leading wing, as discussed previously with regard to the wing alone. This, of course, will produce a variation with sideslip of the pitching moment produced by the flaps which will be dependent upon the flap location. However, a considerably greater effect might be expected from the deflection of ailerons. In the case of ailerons where one is deflected up and the other down, a variation of pitching moment with sideslip does not depend on the loss of lift on the trailing panel being greater than the gain on the leading panel. This is illustrated in sketch 4 for the condition of the wing at positive sideslip with the ailerons deflected to produce a negative roll.
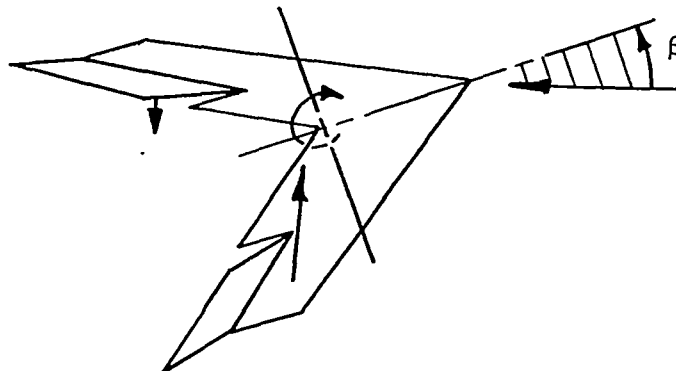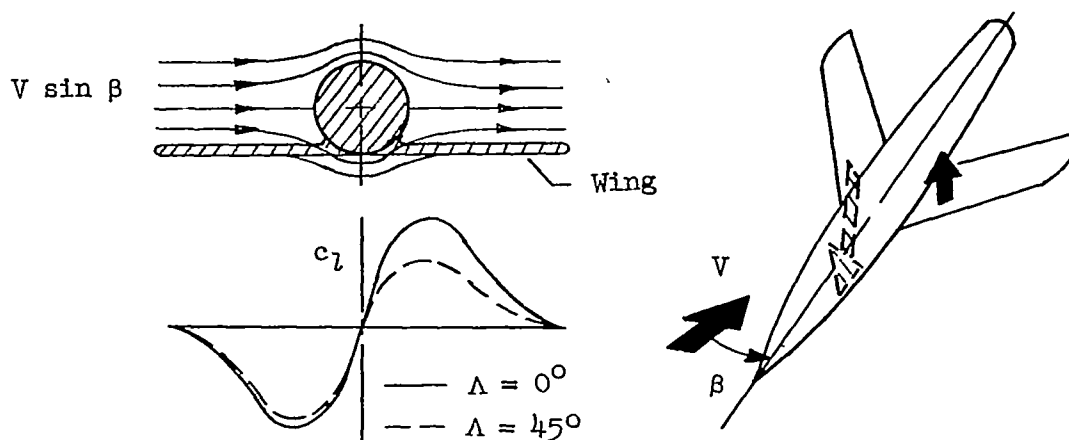
Sketch 4.

The aileron on the advancing wing is producing positive lift which is
increased by the sideslip (due to the lower effective sweep) while the
aileron on the trailing wing is producing negative lift which is decreased
in magnitude by the sideslip. The effects are additive with regard to C_m
and cause (for the case illustrated) a negative pitching moment. Figure 4
presents results from reference 8 of experimentally determined (low-speed)
variations of aileron-induced pitching moments with sideslip for 0°, 45°,
and 60° sweptback wings at an angle of attack of approximately 0°. It
will be noted that, as would be expected, there is relatively little
effect of sideslip for the unswept wing whereas there is an appreciable
effect for the sweptback wings. It should also be noted that the results
are for only one aileron and that with both ailerons deflected the rate
of change with sideslip will be considerably increased.

Additional effects.- As mentioned previously, systematic investi-
gations which include the effect of large angles of sideslip on the
pitching moment are rather sparse and there are undoubtedly factors in
addition to those discussed above which might influence this effect.
For example, large effects on swept wings might be expected between
raked-forward and raked-back tips. Wing devices, such as those used to
alleviate pitch-up tendencies, for example, would be expected to have an
effect, as would changes in loading due to camber or profile shape. It
should also be pointed out that, for the most part, the data presented
have been for relatively low Reynolds numbers and that Reynolds number
could have a noticeable effect, at least at the higher angles of attack.

Wing-Body Characteristics

The discussion so far has dealt only with the wing-alone charac-
teristics. However, the effect of sideslip on pitching moment is modi-
fied by the addition of a fuselage. For example, it appears (see ref. 4)
that the addition of a fuselage to form a midwing configuration results
in at least a slight decrease in sideslip effect. This effect appears
to be small compared to the effects of adding a fuselage to form a high-
or low-wing configuration. The phenomena associated with this effect
are thoroughly discussed by Jacobs in reference 9 and therefore only a
brief summary will be presented here along with subsonic and supersonic
experimental results. As pointed out in reference 9, there are three
main factors contributing to the effect of wing height on the variation
of pitching moment with sideslip. The first of these is dealt with in
sketch 5 which illustrates the effect of the fuselage on the wing.

$V \sin \beta$

c_l

$\Lambda = 0°$

$\Lambda = 45°$

V

β

Wing

Sketch 5.

When a low wing is placed in the flow field of a fuselage in sideslip,
the advancing wing has negative lift induced by the flow field and the
retreating wing has positive lift. For an unswept wing, these forces
are of equal magnitude. However, for a sweptback wing, the retreating
wing has greater sweep (by an increment equal to twice the sideslip
angle) than the advancing wing and therefore is less affected by the
fuselage-induced angle, and the resulting asymmetrical load distribution
produces an overall negative lift increment due to the fuselage flow
field. Since this load is concentrated near the fuselage, it is usually
forward of the unsideslipped aerodynamic center and therefore produces
a negative pitching moment for sweptback wings in the low position and
positive for sweptback wings in the high position.

The second factor is illustrated in sketch 6 and consists of the effect of the wing on the fuselage loads.
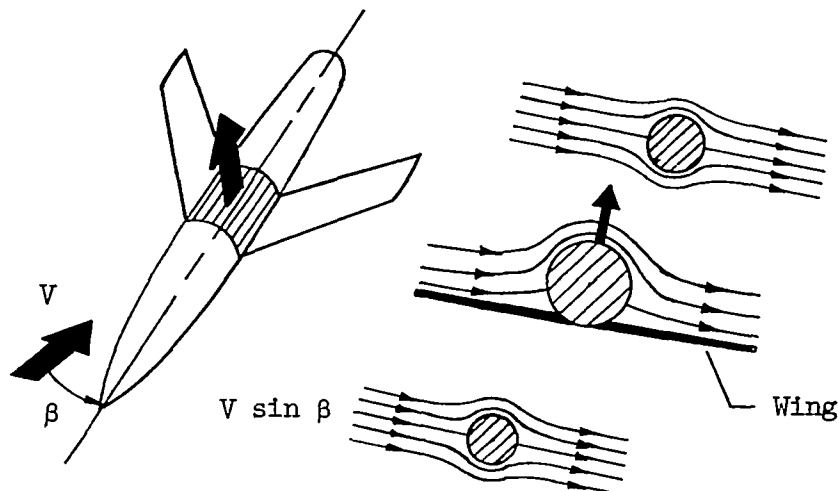
Sketch 6.

For a midwing position the crossflow about the fuselage is symmetrical; however, for a high or low wing the flow in the vicinity of the wing root chord is unsymmetrical as illustrated by the sketch (low wing). This flow would be expected to be somewhat similar to the flow about a cylinder with circulation and produces lift on the fuselage in the vicinity of the wing root (positive lift for low wing and negative lift for high wing). Calculations of this effect, of course, require that the position of the stagnation point be known. With low wings this fuselage load usually produces a positive pitching moment for sweptback wings and a negative moment for unswept wings with increasing sideslip.

The third factor is illustrated in sketch 7 and consists of the effect on the fuselage of the wing downwash associated with wing height.
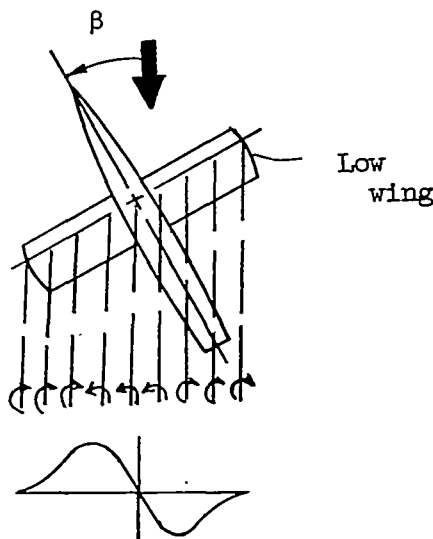
Sketch 7.

Sketch 7 illustrates the case of a low wing at positive sideslip. The spanwise distribution of the increment of load associated with the low wing, as previously discussed in connection with sketch 5, is shown along with the corresponding trailing vortices. In general, the fuselage will contribute a negative pitching-moment increment due to wing position for a low wing and an positive increment for a high wing. In connection with the downwash effect it should be pointed out that for small values of wing span to body length (to the rear of the wing) or for extremely large angles of sideslip, the downwash due to the angle-of-attack loading may be important and, of course, would exist even for a midwing location.

When the three effects described above are combined, the total increment of pitching moment due to sideslip caused by wing position is positive for high wings and negative for low wings. The overall effect of wing height as obtained experimentally at low subsonic speeds (ref. 9) for an unswept and sweptback wing is presented in figures 5 and 6 and the trends expected from the preceding concepts are clearly borne out. It should also be pointed out that in reference 9 good correlation with theoretical calculations based on the above concepts is indicated.

Figure 7 presents the experimental effect of wing height on the variation of pitching moment with sideslip for a sweptback wing at a Mach number of 2.01 (ref. 10). The effect of wing height is somewhat similar to that obtained for the sweptback wing at low subsonic speeds

(see fig. 6) but the effect of sideslip for the midwing configuration is negligible.

Although there is little or no information with regard to wing height at transonic speeds, it would appear, from the subsonic and supersonic results, that the trends would be similar to those presented. Inasmuch as the effect of sweep on lift is greatest at transonic speeds (see ref. 11 for example) one might expect the magnitude of the wing-height effects to be greatest in the transonic speed range.

Horizontal-Tail Characteristics

The direct effect of sideslip on the pitching moment contributed by the horizontal tail can be estimated with the aid of experimentally determined reduction in lift due to sideslip (see section entitled "Wing Characteristics"). Unfortunately, however, interference effects such as loads induced on the horizontal tail by the vertical tail and the fuselage flow field can be large. Although these effects are difficult to isolate with the experimental data that are available, an attempt will be made in the following sections to illustrate some of these effects.

Vertical-tail effect.- The vertical tail in sideslip induces loads on the horizontal tail. For small angles of sideslip the lift induced on the horizontal tail is negligible since the induced load distribution (see ref. 12) is antisymmetrical, as illustrated in sketch 8 and results in only a rolling moment.
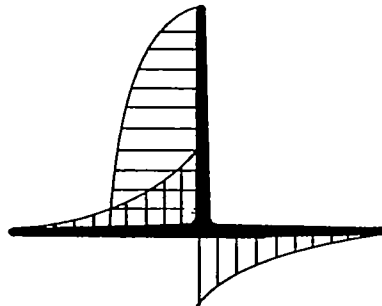
Sketch 8.

Sketch 8 represents a condition of small positive sideslip with the horizontal tail in the low position. For a horizontal tail in the high position, the horizontal-tail loading would be reversed, causing a rolling moment of opposite sign but still producing zero net lift. At large angles of sideslip with swept horizontal tails, the loading will no longer be antisymmetrical because of the change in lift effectiveness

of the panels caused by the difference in effective sweep between the
advancing and retreating panels of the horizontal tail. This, of course,
results in a net lift induced on the horizontal tail which is a function
of sideslip and tail height. The effect of tail height is illustrated
in sketch 9 for large positive sideslip angles.
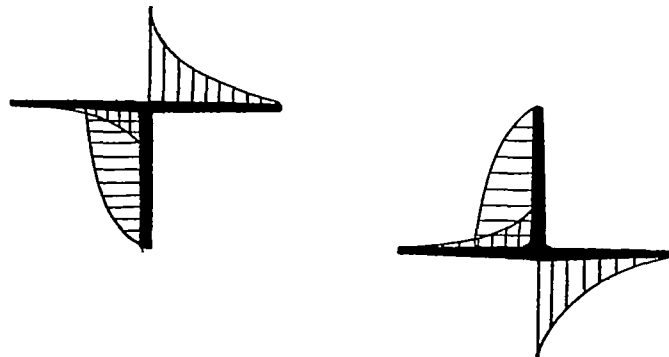
Sketch 9.

It will be noted that a net positive lift is induced on the high hori-
zontal tail (sign of net lift is independent of direction of sideslip)
which will result in a negative pitching moment for a tail-aft airplane,
whereas the low tail will produce a positive pitching moment. Some
experimental evidence of this effect of the vertical tail for various
horizontal-tail heights is presented in figure 8. The top part of the
figure presents data obtained at a Mach number of 2.01 (ref. 10) for a
complete configuration. The bottom two parts of the figure present
results from unpublished tests in the Langley high-speed 7- by 10-foot
tunnel for two body-tail configurations at a Mach number of 0.80. The
pitching-moment coefficients for the body-tail configuration are based
on wing dimensions which result in tail volumes $S_t l_t / S_w \bar{c}$ of 0.446

and 0.234 for the sweptback and delta tails, respectively. These com-
pare with a value of 0.427 for the supersonic model. In order to iso-
late as well as possible the effect of horizontal-tail location on the
vertical-tail interference, the data are presented at 0° angle of attack
and, in the case of the complete configuration, a midwing position. It
will be noted that in all three cases the experimental results substan-
tiate the expected trends (negative increments due to sideslip for high
tails) and that the magnitude of the effect is rather large at sideslip
angles greater than about 5°.

Effect of fuselage flow field.- The wake characteristics of an air-
craft configuration in sideslip can be influenced to a considerable
extent by the fuselage. This, of course, can produce a large effect on
the horizontal-tail contribution to the pitching moment due to sideslip.
Some examples of this effect are shown in figures 9 and 10. Figure 9

presents low-speed pitching-moment data (ref. 13) and a wake-survey pic-
ture for an aircraft configuration. The wake-survey picture was made
just to the rear of the horizontal-tail position by means of a tuft grid
placed normal to the stream direction (see ref. 14 for details of the
tuft-grid technique). For the tuft-grid picture the vertical and hori-
zontal tails were removed and small-diameter circular rods were placed
at three vertical positions on a vertical rod for orientation purposes,
with the upper one corresponding to the top of the vertical tail and
with the lower one on the bottom of the fuselage. The picture was taken
at an angle of attack of 10° and an angle of sideslip of 25° and clearly
shows, in addition to the wing-tip vortices, a strong (counterclockwise)
vortex at the midtail location. The origin of this vortex was traced
(by means of a tuft pole survey) to a point on the fuselage ahead of
the canopy. It should be pointed out that tests with and without the
canopy indicated little effect of the canopy on the fuselage vortex.
It therefore appears that this vortex is associated with the well-known
crossflow separation on bodies inclined to the wind. Although a second
fuselage vortex would be expected to be produced somewhat below the one
shown, it is not apparent in the flow picture. There is the possibility,
however, that this vortex is intercepted, for this combination of angle
of attack and sideslip, by the wing (see sketch 10) and through its
effect on the wing loading is effectively distributed across the wing
wake.
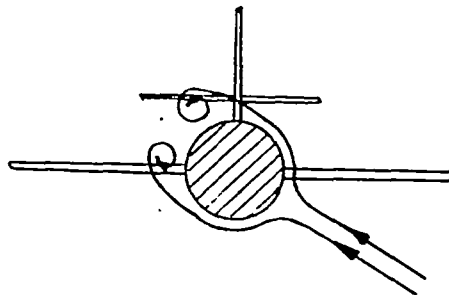
Sketch 10.

As the angle of sideslip increases from zero, the vortex increases in
strength and moves away from the plane of symmetry. Both of these
effects cause increases in the load induced on the horizontal tail by
this vortex and can cause a considerable variation of pitching moment
with sideslip. This is illustrated in figure 9 by the experimental
pitching-moment data, for the configuration shown in the sketch, plotted
as a function of sideslip angle for various angles of attack. Also
shown is the horizontal-tail-off data for an angle of attack of 0.3°.
The results indicate a large effect of sideslip on the tail contribution
to the pitching moment which appears to be associated with the fuselage
vortex. No definite conclusion with regard to the effect of angle of
attack can be made inasmuch as tail-off data were obtained only at one

angle of attack. Further evidence that this variation is associated
with the fuselage vortex is contained in the fact that for this horizontal-
tail location the vertical-tail effect (see the previous section) would
be either in the opposite direction or negligible.

Figure 10 presents somewhat similar results (ref. 15) obtained for
a fuselage-tail configuration (wing off) at low subsonic speed. Here
again the horizontal tail is in a location where the vertical-tail
effect would be expected to result in positive increments of the tail
contribution due to sideslip, but negative increments result at an angle
of attack of 0.2° apparently from the fuselage-vortex effect. At an
angle of attack of 22.2° it will be noted that the variation with side-
slip angle was reversed. A large reduction in the sideslip effect would
be expected at this angle of attack inasmuch as it is on the flat portion
of the tail lift curve. The actual reversal of sideslip effect that
occurs may be due to the effect of the vertical tail on the horizontal
tail (see fig. 8).

Inasmuch as the preceding experimental results have indicated a
strong effect of fuselage vortices on the variation of pitching moment
with sideslip angle, it appears that information with regard to the
effect of fuselage shape on the origin, strength, and path of these
vortices is urgently needed. With regard to these fuselage vortices
the reader is referred to reference 16 which presents a preliminary study
of their effect on tail loads for relatively simple body shapes.

Aileron effect.- It was shown in the section "Wing Characteristics"
that ailerons can have a rather sizable effect on the variation with
sideslip of the pitching-moment coefficient of swept wings (see fig. 4).
However, in addition to this effect the ailerons can, for certain con-
figurations at least, have a large effect on the variation of the
horizontal-tail pitching-moment contribution with sideslip. Some results
of a recent investigation of this effect conducted in the Langley 300 MPH
7- by 10-foot tunnel are presented in figure 11. The model consisted of
a 45° sweptback wing of aspect ratio 4.0 having a taper ratio of 0.3 and
NACA 65A006 airfoil sections parallel to the plane of symmetry mounted
in the midwing position on a body of revolution, a 45° sweptback hori-
zontal tail mounted on the fuselage center line, and a 45° sweptback
vertical tail. Both inboard and outboard ailerons were investigated
and the results are presented for the condition of the right aileron
deflected down 10° and the left up 10° (producing left roll). Tail-off
results are presented in the lower portion of figure 11 for an angle of
attack of 6.5° for the inboard ailerons (no tail-off data obtained for
outboard ailerons). The tail-off results are in agreement with the pre-
viously discussed aileron effects (see fig. 4). In the middle portion
of figure 11 the tail-on results are shown for an angle of attack of
6.5° and for the undeflected aileron the low-tail effect shown in fig-
ure 8 is in evidence. With the inboard ailerons deflected it will be

noted that the aileron effect is opposite to what it was with the horizontal tail off; that is, with the tail on the inboard ailerons contribute a positive increment of pitching moment for positive sideslip angles. It will be further noted that, with the outboard ailerons deflected, negative pitching-moment increments are produced. This large effect of aileron location is apparently associated with the relationship between the horizontal tail and the aileron downwash field. This is illustrated in sketch 11 which compares inboard and outboard ailerons at a sideslip angle of about 20°.
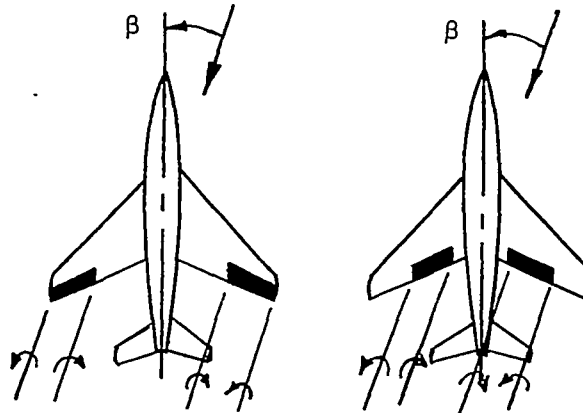
Sketch 11.

The vortex system represents ailerons deflected so as to produce a negative rolling moment. It will be noted that the tail pitching moments induced by the aileron flow field would be expected to be of opposite sign for this particular combination of aileron location and sideslip angle with the outboard ailerons contributing a negative moment and the inboard a positive moment. Returning now to figure 11, the results at an angle of attack of 12.7° indicate that the effect of aileron deflection has reduced somewhat because the low tail has moved somewhat below the aileron wake. This implies that the effect of aileron deflection on the tail increment of pitching moment will depend upon the horizontal-tail location in addition to the aileron location and the angle of attack.

CONCLUDING REMARKS

Based on this brief summary of representative data with regard to the variation of pitching-moment coefficient with sideslip angle, it is evident that the variation can be large and that it depends upon a rather large number of variables. Although data are rather meager, it appears that several rather definite conclusions can be determined from this information with regard to the effect of these variables. For .

example, it appears that negative increments of pitching moments due to positive sideslip angles are associated with wing sweep (below the angle of attack for pitch-up), low wing position, high horizontal-tail location (relative to vertical tail), fuselage vortices, and outboard ailerons producing negative roll. However, considerably more experimental information is needed with regard to the effect of sideslip on pitching moment, especially at transonic and supersonic speeds, for large sideslips and angles of attack.

Langley Aeronautical Laboratory,
    National Advisory Committee for Aeronautics,
        Langley Field, Va., May 2, 1955.

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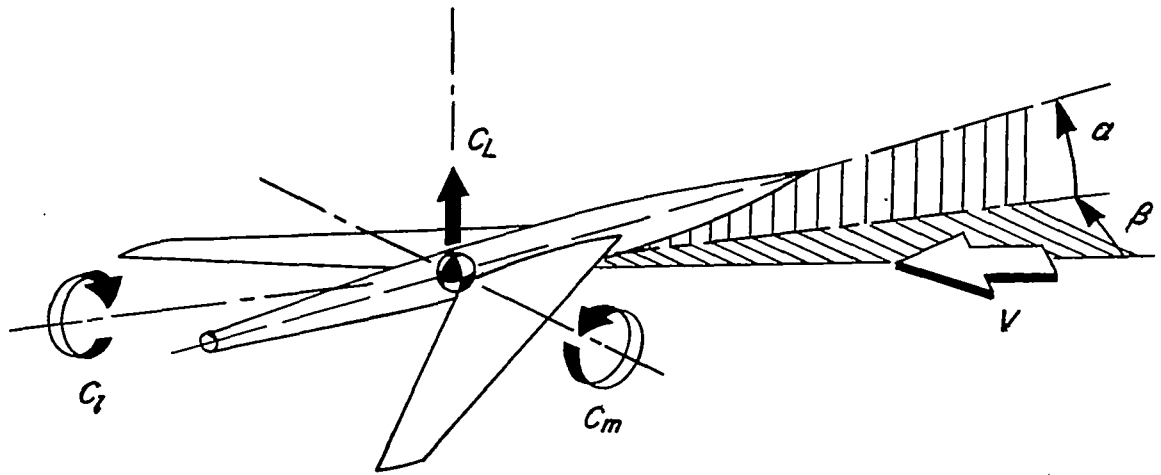
Figure 1.- System of axes used (stability) showing positive direction of
forces, moments, and angles.
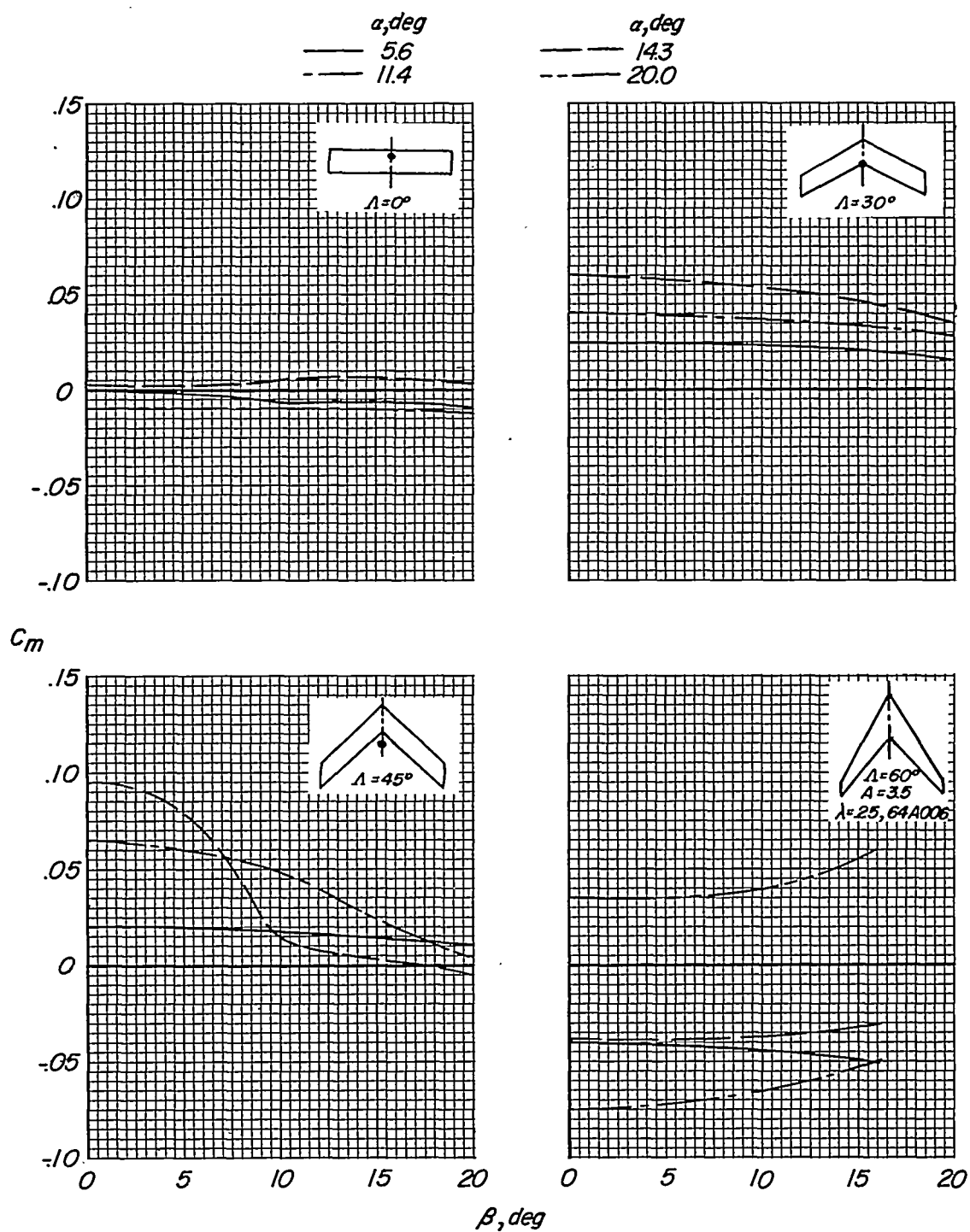
Figure 2.- The variation of pitching-moment coefficient with sideslip
angle for various sweptback wings at low subsonic speeds. A = 5.2;
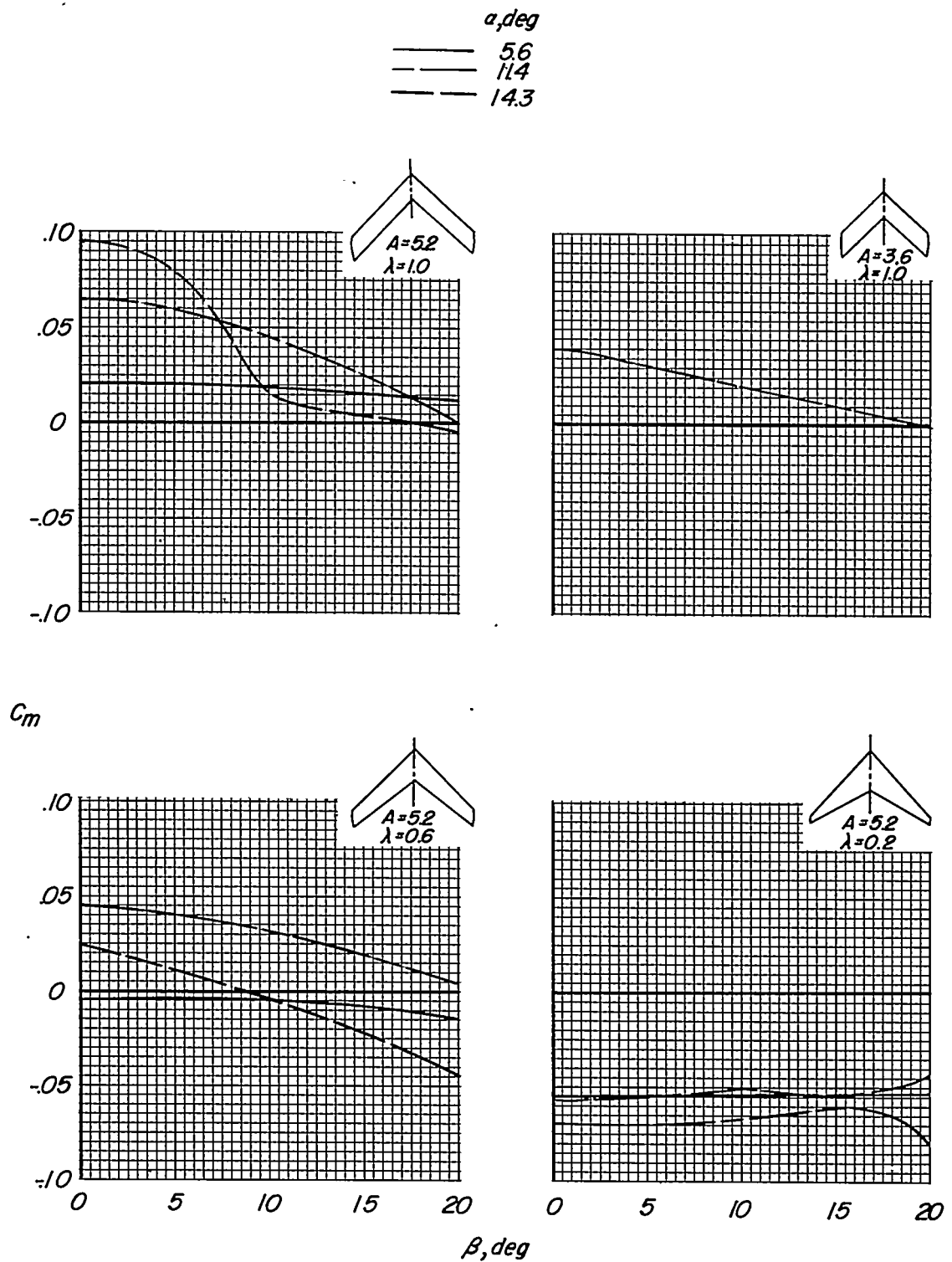λ = 1.0; NACA 23012 airfoil section (except where noted).

Figure 3.- The variation of pitching-moment coefficient with sideslip angle for wings of various aspect ratios and taper ratios at low subsonic speeds. Λ = 45°; NACA 23012 airfoil section.
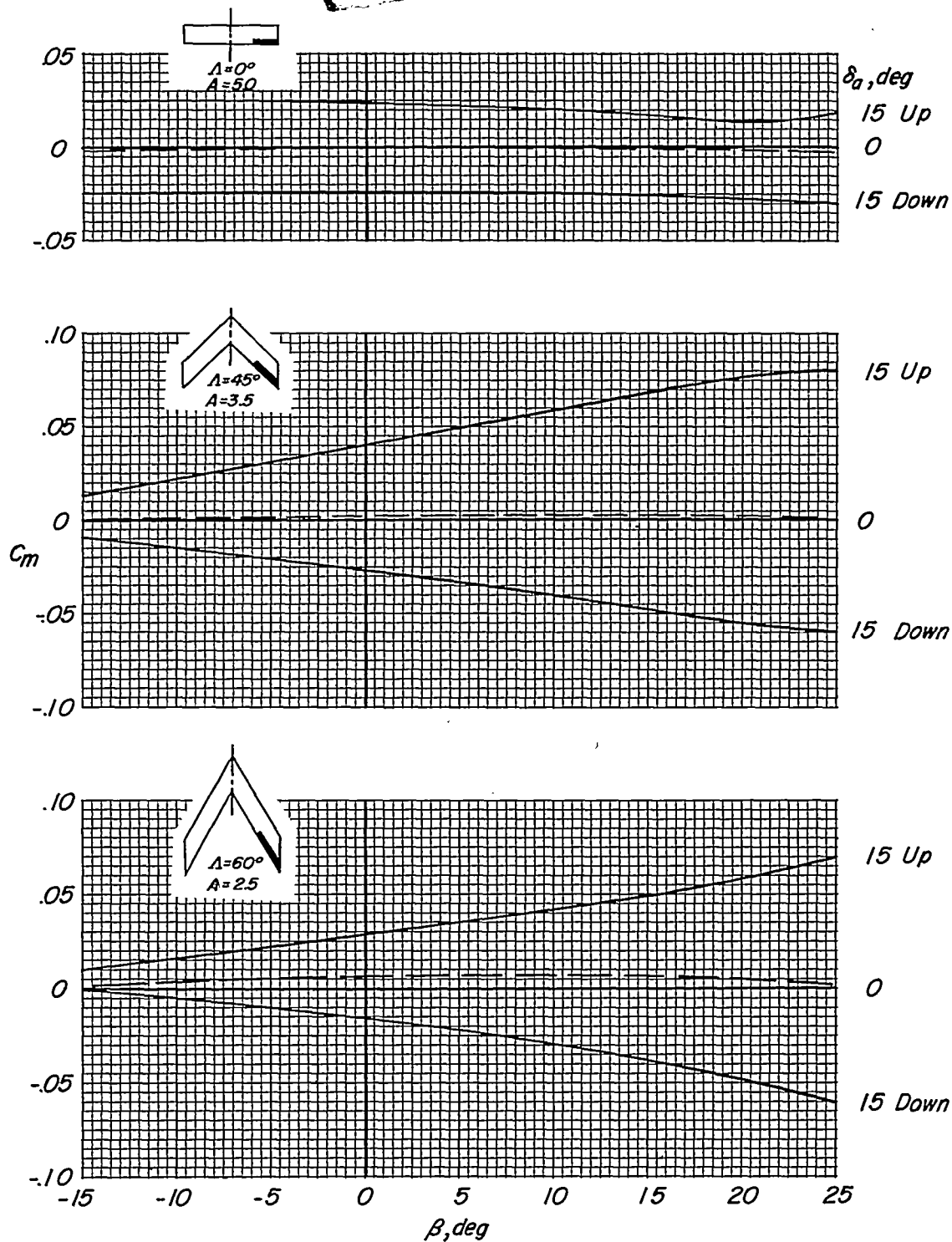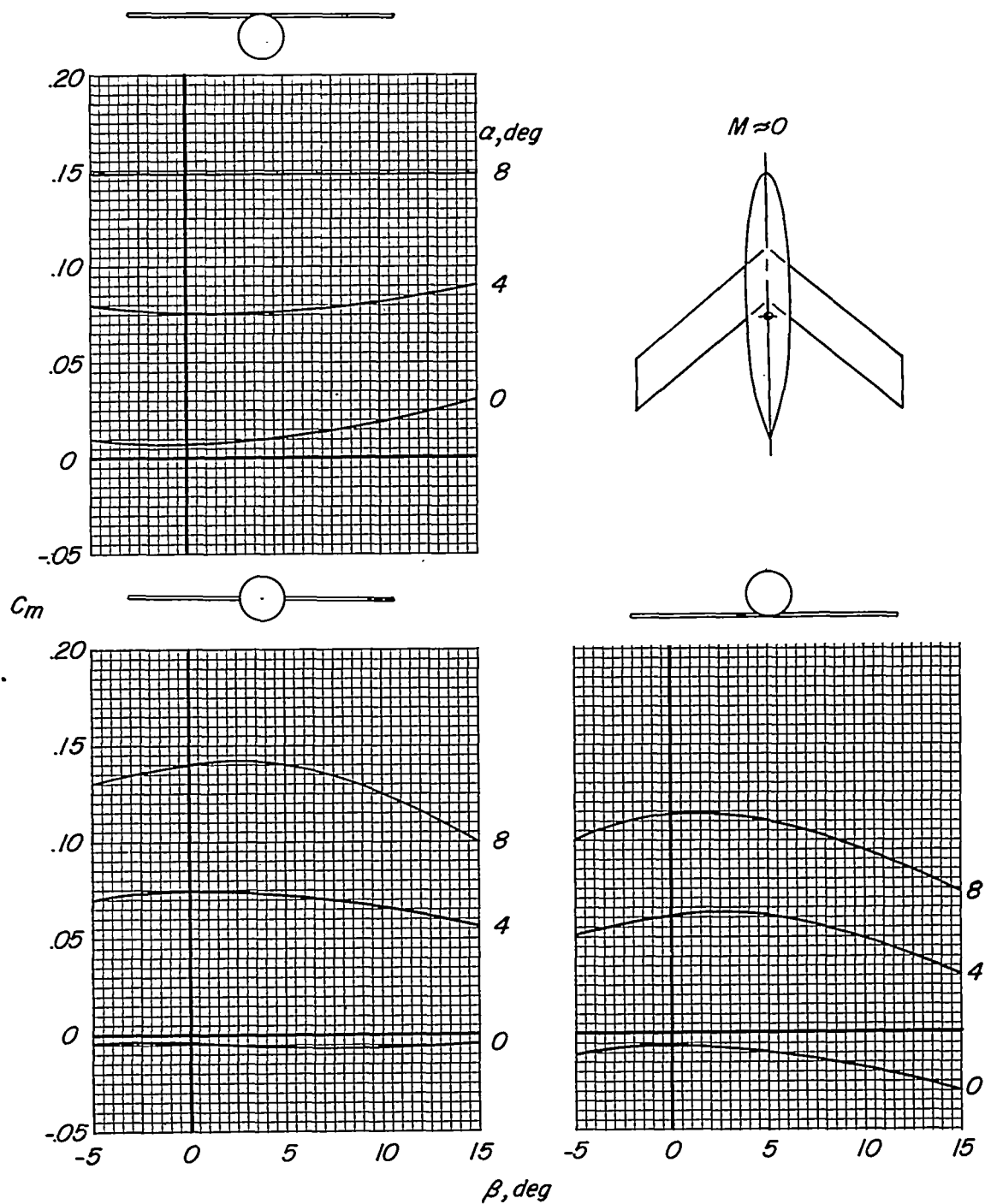
Figure 4.- Effect of right-aileron deflection on the variation of pitching-moment coefficient with sideslip angle for various swept wings at low subsonic speeds. $\lambda = 1.0$; $\alpha \approx 0°$.
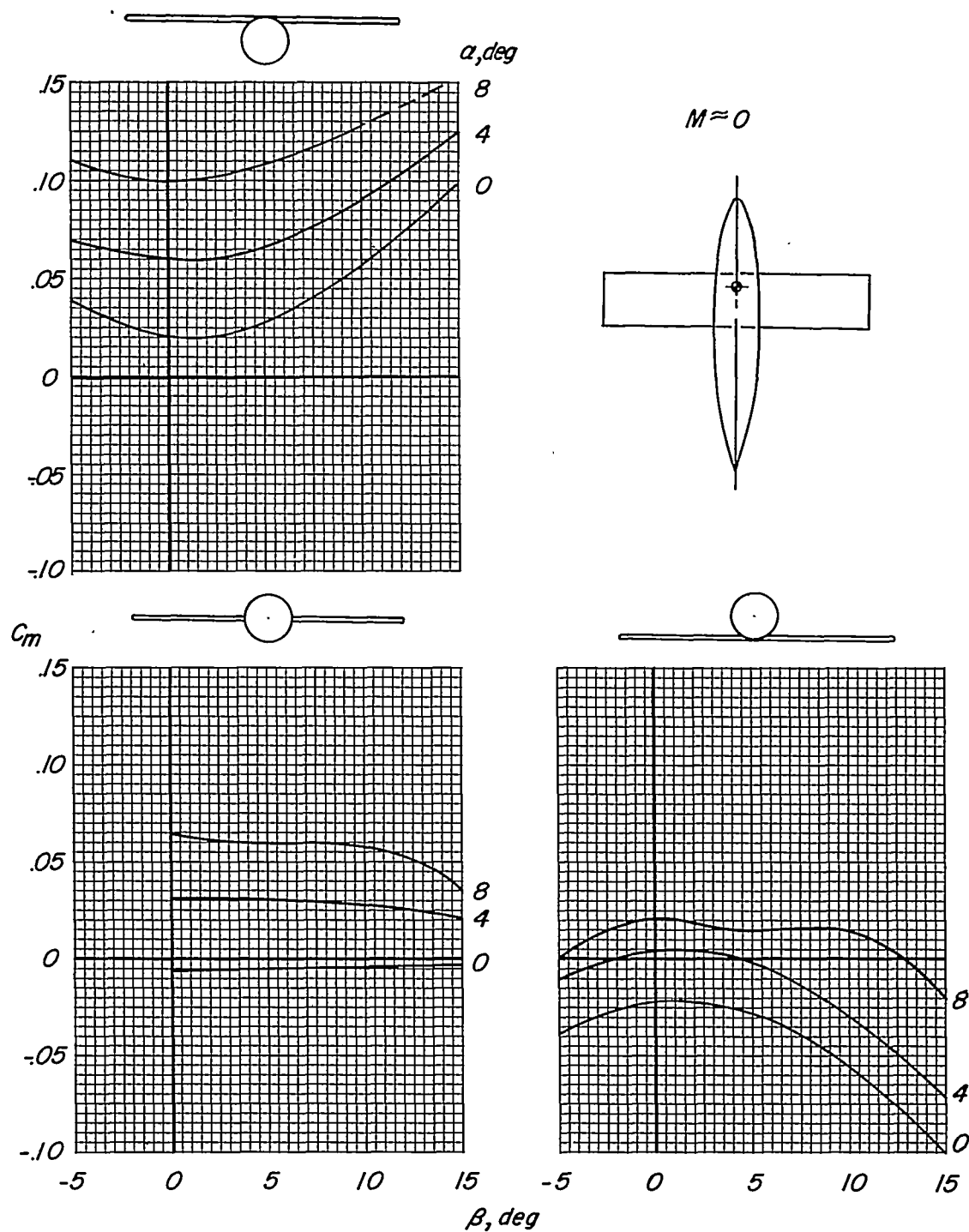
Figure 5.- Variation of pitching-moment coefficient with sideslip angle
for various wing vertical positions at low subsonic speeds. $\Lambda = 0°$;
$A = 5$; $\lambda = 1.0$.

Figure 6.- Variation of pitching-moment coefficient with sideslip angle
for various wing vertical positions at low subsonic speeds. $\Lambda = 45°$;
$A = 5$; $\lambda = 1.0$.
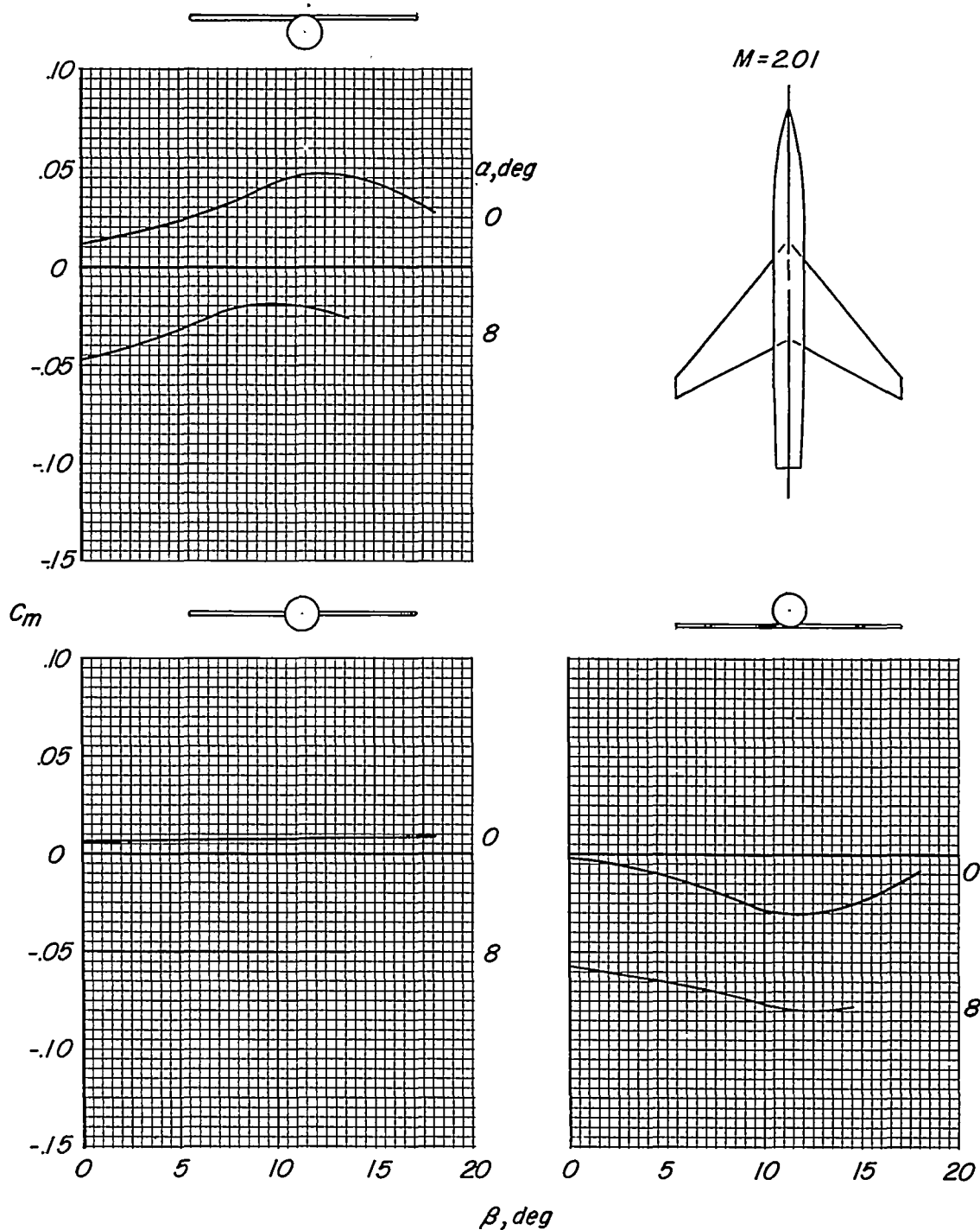
Figure 7.- Variation of pitching-moment coefficient with sideslip angle for various wing vertical positions at a Mach number of 2.01. $\Lambda = 45°$; $\lambda = 0.2$; NACA 65A004 airfoil section.

M=2.01
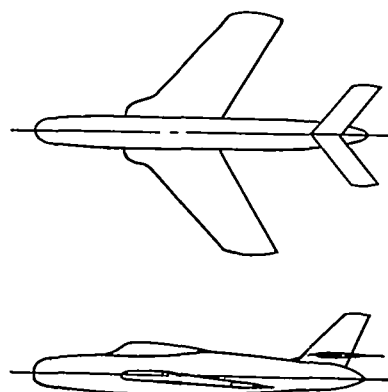
Tail off

$\dfrac{S_t l_t}{S_w \bar{c}} = 0.427$

C_m

M=0.80

$\dfrac{S_t l_t}{S_w \bar{c}} = 0.234$

M=0.80

$\dfrac{S_t l_t}{S_w \bar{c}} = 0.446$

β, deg
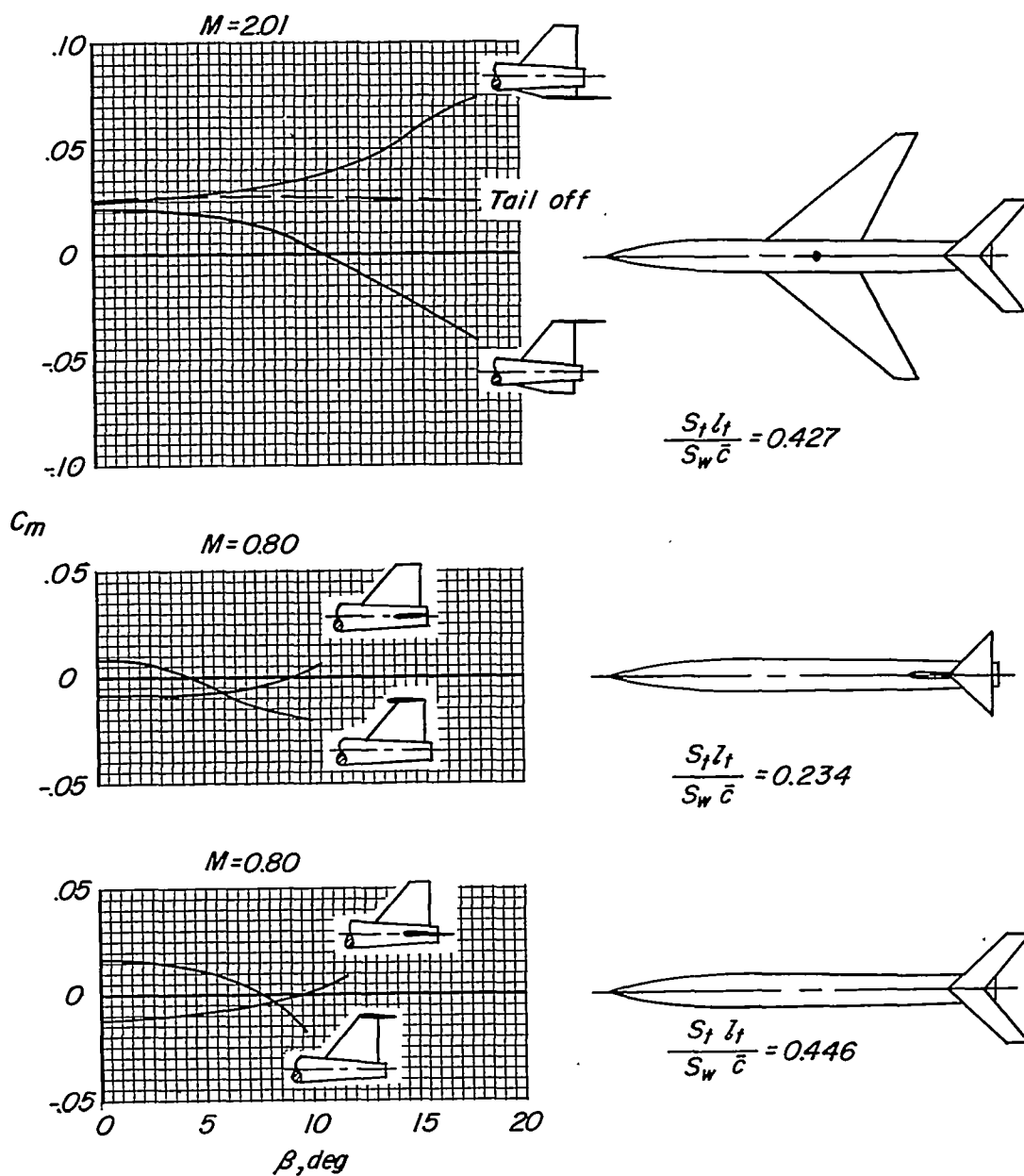
Figure 8.- Variation of pitching-moment coefficient with sideslip angle
for various horizontal-tail positions. $\alpha = 0^\circ$.
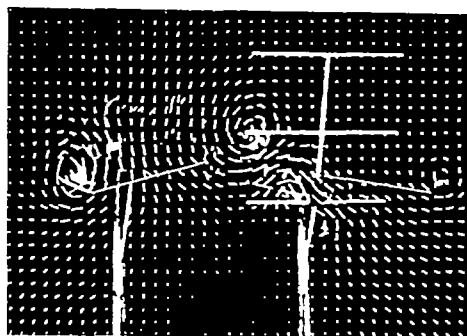
Tuft-grid photograph
$a = 10°$; $\beta = 25°$

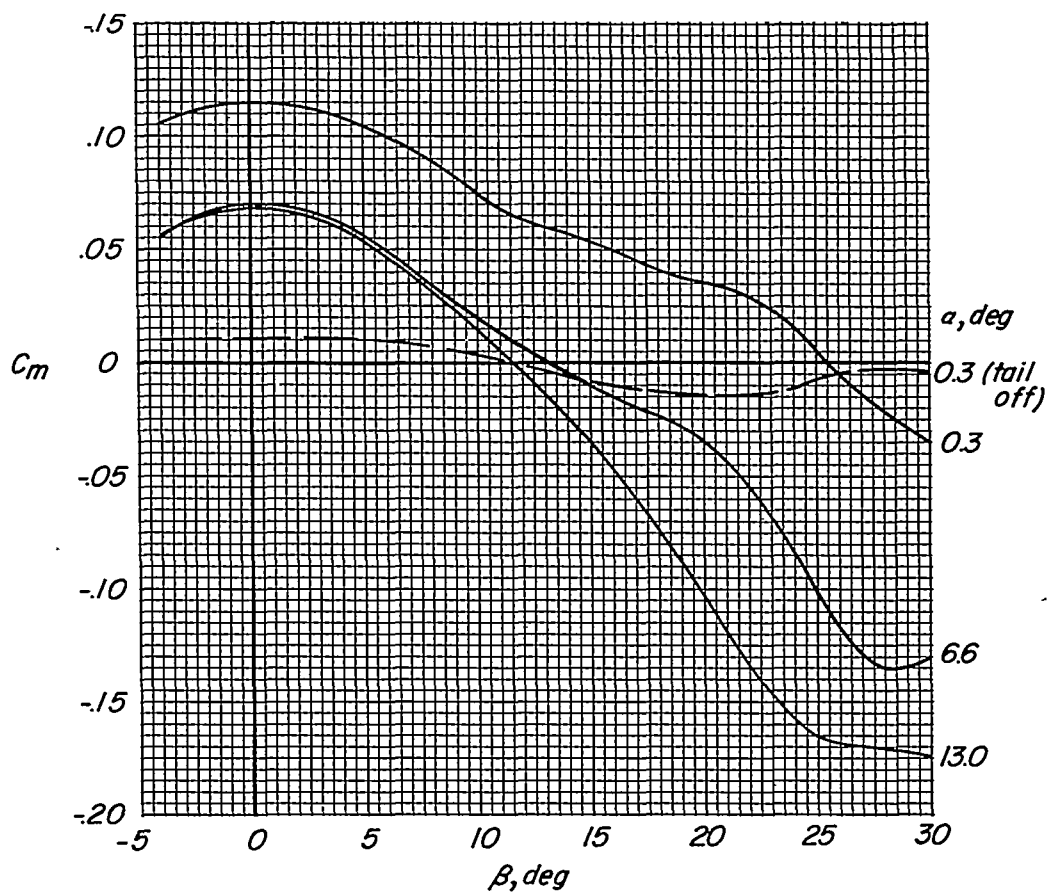Figure 9.- Effect of fuselage vortex on the variation of pitching-moment
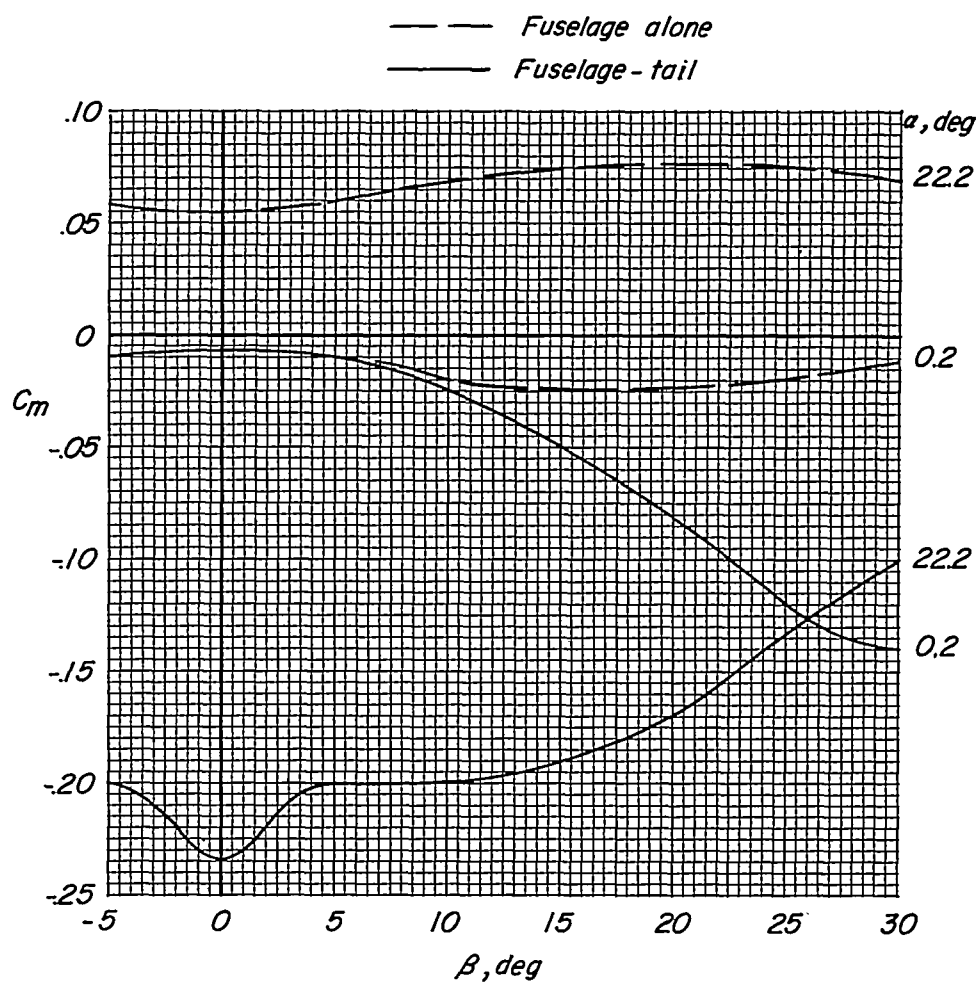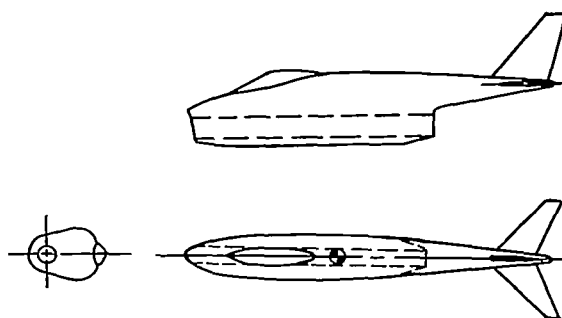coefficient with sideslip angle at low subsonic speeds.

Figure 10.- Variation of pitching-moment coefficient with sideslip angle for a fuselage-tail configuration at low subsonic speeds.
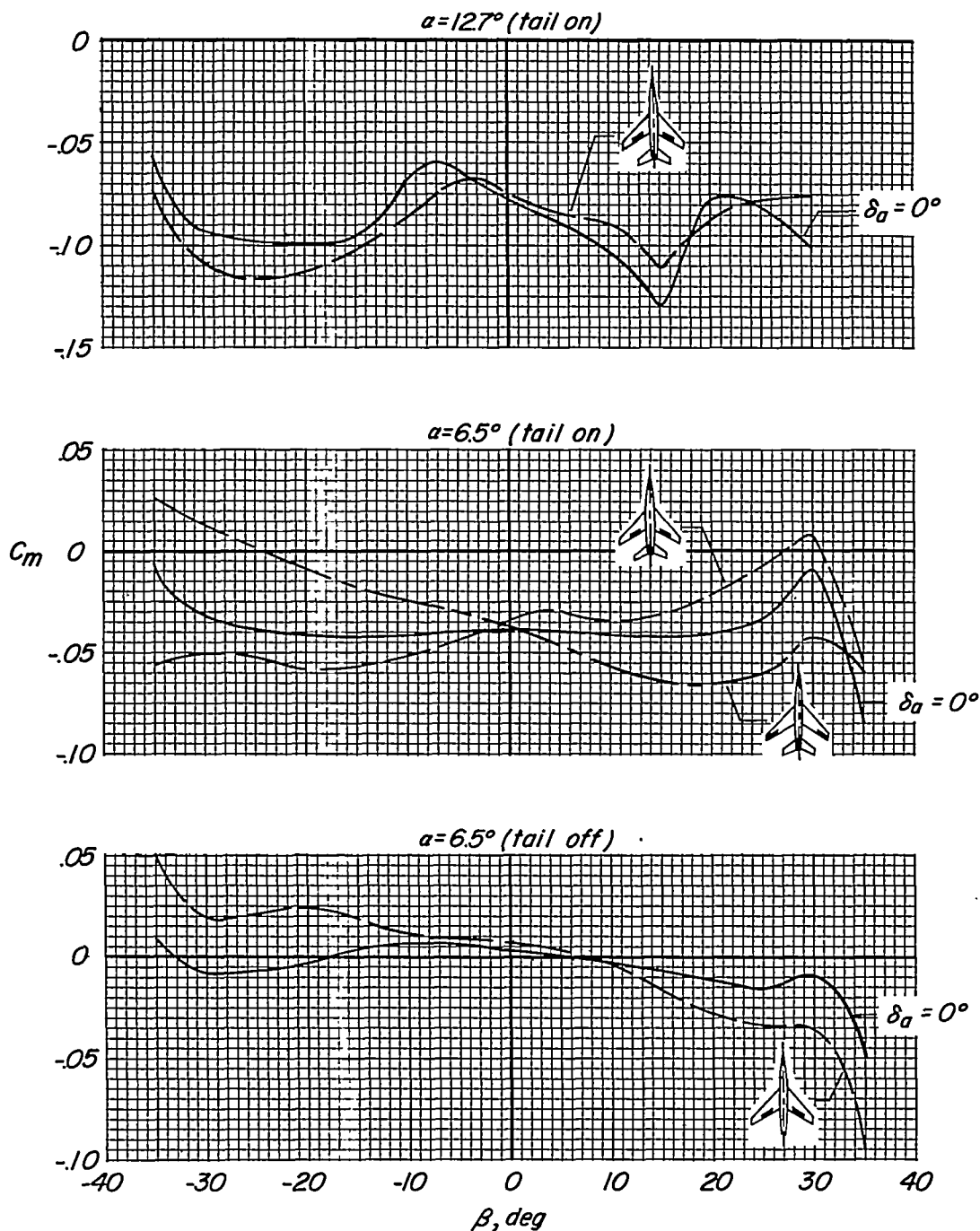
$a=12.7°$ (tail on)

$a=6.5°$ (tail on)

$a=6.5°$ (tail off) ·

β, deg

Figure 11.- Variation of pitching-moment coefficient with sideslip angle
for various aileron configurations. Right aileron down 10° and left
aileron up 10°.